Nano World Journal

https://doi.org/10.17756/nwj.2022-097

Research Article

Open Access

Experimental Investigations of Effect of Nano Composites on Performance of VCR System at Variable Capillary Tube Lengths

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Received: January 7, 2022
Accepted: February 25, 2022
Published: March 2, 2022

Citation: Kumar MR, Meher RS, Kumari AS. 2022. Experimental Investigations of Effect of Nano Composites on Performance of VCR System at Variable Capillary Tube Lengths. *NanoWorld J* 8(1): 28-35.

Published by United Scientific Group

Abstract

Vapour compression refrigeration (VCR) system has maximum coefficient of performance (COP) and widely used system all round the world. Due to hazardous chlorine content in Hydrofluorocarbon (HFC) refrigerants, which deplete ozone layer, various attempts were made by Heating Ventilating Air Conditioning (HVAC) engineers to replace the freons with alternate refrigerants. The present scope of the paper was to prepare an azeotropic solution with R600a, agglomerated with composite of TiO_2 and CuO of size less than 100 nm in size. The operating pressures, temperatures of low pressure and high-pressure regions were discussed with R600a, and R600a with nano composition. The experiments were performed on existing VCR system with dual refrigerant test capacity. The COP of VCR system using R600a agglomerated with nano composites tested for various capillary lengths were reported. It was observed that due to enhancement of thermal conductivity of the R600a with nano composites, the COP of the VCR system has increased and the system worked stable at elevated condenser temperatures.

Keywords

TiO_2, CuO, COP, VCR system

Introduction

VCR system is used universally to meet the growing demand Energy is main source which runs the world, there are various sources of energy available naturally, need to convert it to required form for its effective utilization. The energy consumption for the HVAC equipment is keep on increasing in view of maintaining certain required climatic conditions for social comfort and industrial applications. VCR system is well known for its upright performance both in commercial and industrial applications. The VCR system utilizes a coolant known as refrigerant for energy transfer purpose, it absorbs heat from a low temperature system and discards it to high temperature system. To run the VCR system energy is needed. The power consumption of VCR system depends on operating temperatures of evaporator, condenser and the kind of refrigerant used in the system. The selection of refrigerant plays a major role for the VCR system which decides the energy expended by the system. Not only energy consumption, it should also be ecofriendly. The refrigerant used for domestic purpose is R134a. The problem with R134a is its Global Warming Potential value which is 1300. As per Kigali amendment 197 countries have agreed to reduce the HFC's up to 80% by the year 2028. As the world is looking for an alternative and ecofriendly refrigerant the research is going on in these areas. The R600a can be an alternative ecofriendly refrigerant which has zero ODP and zero Global Warming Potential values. The experimental work was conducted on VCR system with R600a as refrigerant and obtained results were compared with added TiO_2 and CuO composite nano materials. The main objective of this work was to observe the performance of VCR system with added nanoparticles.

An experimental study was conducted by [1] using a hydrocarbon mixture consisting propane and isobutane with a ratio of 45.2:54.8 by weight as a replacement for R134a in domestic refrigerator. Latent heat of hydrocarbons is considerably higher than that of R134a, the amount of refrigerant charge can be reduced. A study was carried out with a mixture of propane and iso-butane with a ratio of 50:50 by weight in a domestic refrigerator [2] which worked with 150 g of R134a. The outcomes showed that hydrocarbon mixture reduces the energy consumption by 4.4% and the weight of the refrigerant used was reduced by 40% compared to R134a. By using a hydrocarbon mixture [3], the temperature variations in refrigerator cabin occurs faster and the ON time ratio is less than of R134a. Ghorbani et al. [4] performed the analysis POE/CuO Nano refrigerant in R600a and compared it to POE oil with R600a in a refrigeration system. Three different various POE/CuO mass percentage samples of R600a with POE/CuO of 0.5, 1, and 1.5% were considered for the experiment and compared with pure R600a with POE oil. The result displayed that presence of Nanoparticles in POE lubricant oil increases condensing heat transfer of 4.1%, 8.11%, and 13.7% respectively compared to base fluid. Srinivas [5] performed experimental investigation with LPG as refrigerant and found that energy consumption is drastically decreases with LPG as refrigerant. Elcock [6], TiO_2 nanoparticles were used as additives to enhance the solubility of mineral oil with the HFC refrigerant. It was observed that refrigeration systems using a mixture of HFC134a and mineral oil with TiO_2 nanoparticles appear to give better performance by returning more lubricant oil to the compressor with similar performance to systems using HFC134a. An experimental study on the performance of a domestic refrigerator using Al_2O_3 -R134a Nano refrigerant as working fluid was carried out in the work of Senthil kumar and Elansezhian [7]; It was observed that Al_2O_3-R134a system performance was better than pure lubricating oil with R134a working fluid with 10.30% less energy used with 0.2% volume of the concentration used and also heat transfer coefficient increases with the usage of Nano Al_2O_3. [8] conducted experiment with CuO nano refrigerant and found that density and thermal conductivity was increasing gradually with increase in concentration of CuO. Whereas, when the concentration percentage of R-600a decreases, the density and thermal conductivity decreases. It was observed from the specific heat calculations that as the volume concentration percentage of nanoparticles increases, the specific heat was decreasing eventually. The results indicated that TiO_2-R600a function normally and efficiently in refrigerator. Shengshan Bi [9] studied with refrigerator using pure R600a as working fluids, 0.1 and 0.5 g/L concentrations of TiO_2 -R600a saves 5.94% and 9.60% energy consumption respectively and the freezing rate of nano refrigerant system was faster than pure R600a system. S. A. Fadhilah experimented with nanoparticle suspended into the conventional refrigerant with 1% volume fraction which causes a growth in thermal conductivity about 3121% enhancement from 0.0139 to 0.4477 W m^{-1} K^{-1}. In the previous work, Nair [10] investigated the basic characteristics of the TiO_2-R134a nano-refrigerants. Bi SS [11-15] studies dispersion behavior, thermal conductivity, and flow boiling heat transfer TiO_2 with HFC134a. Saurabh Gupta and Srinivas pendyala [16-19] used the hydrocarbon refrigerants and observed enhancement of performance of VCR system.

Materials and Methods

The experimental set up consist of a VCR system, with variable capillary tube arrangement as shown in Figure 1. The Refrigeration system is design to test the performance of two refrigerants simultaneously. It consists of hermetically sealed compressors, air cooled condenser, series of capillary tubes for variable static thermal load, and an evaporator, which was computer controlled. In built naïve software will provide the necessary salient point operation data to estimate the performance of the refrigerant. Initially check the valves whether they are in closed condition or not. Fix the capillary tube of desired length (8 feet) and evacuate the circuit by using vacuum pump, it removes any moisture content and other gas particles in the refrigeration circuit. Now charge the Refrigerant R-600a into the circuit and check the refrigerant charge. Switch on the apparatus and open the valve of the capillary tube. Keep the thermostat valve to maximum condition and choose the evaporator temperature and start the timer. Note the readings in the digital indicator and time taken for every one-degree drop of temperature. Repeat the experiment until we get the required temperature.

The tests were conducted on VCR system with R600a as refrigerant and R 600a agglomerated with nano material for different condenser temperatures. The suction and discharge pressure of compressor, temperatures at salient points of subsystem of VCR system were noted down. The above procedure repeated for different capillary tube lengths for optimizing its length. To assess the performance of the VCR system a quantity of 7 liters of water taken in the evaporator and time taken to cool the water till there was a drop of 10 degrees centigrade

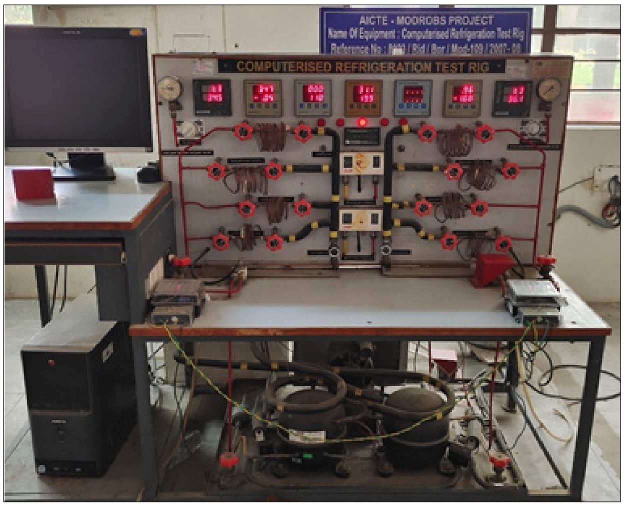

Figure 1: Computerized vapour compression refrigeration system.

was noted down

The TiO_2 and CuO was ground to nano size particles by chemical vapour deposition process and mixed to lubricating oil in the laboratory. The uniform mixing of the TiO_2 and CuO was ensured with continuous magnetic stirrer for 72 hours and uniform solution (approximately) was obtained. The TiO_2 and CuO powder was mixed with lubricating oil and then the VCR system was charged with R600a. This will ensure proper mixing of the TiO_2 and CuO with R600a in dynamic condition of VCR system. The procedure for adding of TiO_2 and CuO nano particles were shown in Figure 2. As the compressor was hermetically sealed, the lubricating oil was in contact with the R600a during operation, hence the nanoparticles associated with lube oil will mix with refrigerant and enhance the refrigeration effect of VCR system. The lubricating oils (Synthetic oils), such as glycols, esters and alkylbenzenes (AB) has been used in the refrigeration applications earlier without any problem. The CFC refrigerants such as R12, R13, R113, R114, and R115 are using mineral oil or alkylbenzene as their lubricants. Similarly, HCFC refrigerants such as R22, R123, R401A and R409A are also using these lubricants in their design. In recent years CFC and HCFC refrigerants usage began to dwindle due to their ozone-unfriendly properties. Usage of new HFC refrigerants such as R23, R32, R134a, R407A, R407C, and R410A has been increasing in HVAC equipment. These new refrigerants use Polyol esters or POE as lubricant. One setback of POE is that it absorbs moisture several times more compared to mineral based oils. Hence proper procedures must be followed when handling these oils to reduce the contact oil with the atmosphere. Metal containers are used instead of plastic containers to avoid moisture from entering the containers.

Results and Discussion

Experiments were conducted on vapour VCR system test rig with R600a as working fluid at three condenser temperatures of 27 ⁰C, 33 ⁰C, and 37 ⁰C at three varying lengths of capillary tube 8, 10 and 12 feet. The experiment was repeated with R600a agglomerated with TiO_2 and CuO powder 0.1% (0.07% of CuO + 0.03% of TiO_2) in 300 ml of lubricating oil. TiO_2 nanoparticles usually was used for nanofluids preparation due to the higher thermal conductivity value (4 - 11.8 W/m.K), safe material, easily obtained, and are chemically stable. The typical value of thermal conductivity is 33 W/m.K for CuO.

At 27 ⁰C, for a capillary length of 8 feet, the temperature at inlet of compressor (T_1), Temperature at outlet of compressor (T_2), temperature at outlet of condenser (T_3), temperature at outlet of evaporator (T_4), temperature of thermal load in evaporator (T_5), with delivery pressure (condenser pressure P_d), suction pressure (evaporator pressure p_s) and work input to the compressor. Pull down time in seconds was estimated. The same procedure was adopted for 10 feet and 12 feet length capillary tube, at various ambient temperatures of 33 ⁰C and 37 ⁰C was performed. Table 1 shows the results obtained for R600a refrigerant without nanoparticles and Table 2 displays the results with nanoparticles.

The length (L) of capillary tube was expressed in foot, Temperatures in degrees centigrade, pressure in kg cm^{-2}, work input to the compressor in watts and pull down time in seconds. The evaporator was dry evaporator with a thermal load of 7 liters of water kept at prescribed evaporator temperature T_5. The COP was evaluated for various observations with R600a as refrigerant.

For 8 feet capillary tube length, the time taken for 10 degrees drop in water temperature for R600a as refrigerant at 27 ⁰C was found to be 1320 seconds and for R 600a with added nanoparticles was 660 seconds which was half of the time taken for pure R600a as shown in Figure 3a, it was due to the fact that nanoparticles present in the refrigerant improves the heat transfer capacity in evaporator. As the capillary length increases from 8 feet to 10 feet and 12 feet, the time taken gradually increases for R600a with nano refrigerant due increase in frictional coefficient. The experimental outcomes obtained for 10 feet and 12 feet capillary length were plotted in the graphs shown in Figure 3b and Figure 3c.

The pull down test results of R600a and R600a agglomer-

Figure 2: Adding of nanoparticles to mineral oil and injecting it to compressor.

Table 1: Experimental observations at various ambient temperatures and different length of capillary tubes for R600a.

L	Ambient	T_1	T_2	T_3	T_4	T_5	P_d	P_s	W	Time
8	27 ^{0}C	31.9	45.5	40.7	4.2	22	4.23	0.87	197	1320
8	33 ^{0}C	34.3	52.7	47.3	5.8	22	4.92	1.15	195	1080
8	37 ^{0}C	35.9	54.8	49.6	8.8	22	5.22	1.29	200	1140
10	27 ^{0}C	30.4	45.9	40.9	3.2	22	4.35	0.63	192	1500
10	33 ^{0}C	34.0	52.2	46.9	4.6	22	5.05	1.05	193	1160
10	37 ^{0}C	36.1	54.0	49.0	9.0	22	5.43	1.16	203	1020
12	27 ^{0}C	31.1	45.2	40.4	2.6	22	4.35	0.53	191	1620
12	33 ^{0}C	34.4	51.9	46.8	5.4	22	5.05	0.91	187	1200
12	37 ^{0}C	35.0	54.6	49.2	5.0	22	5.33	1.11	199	1260

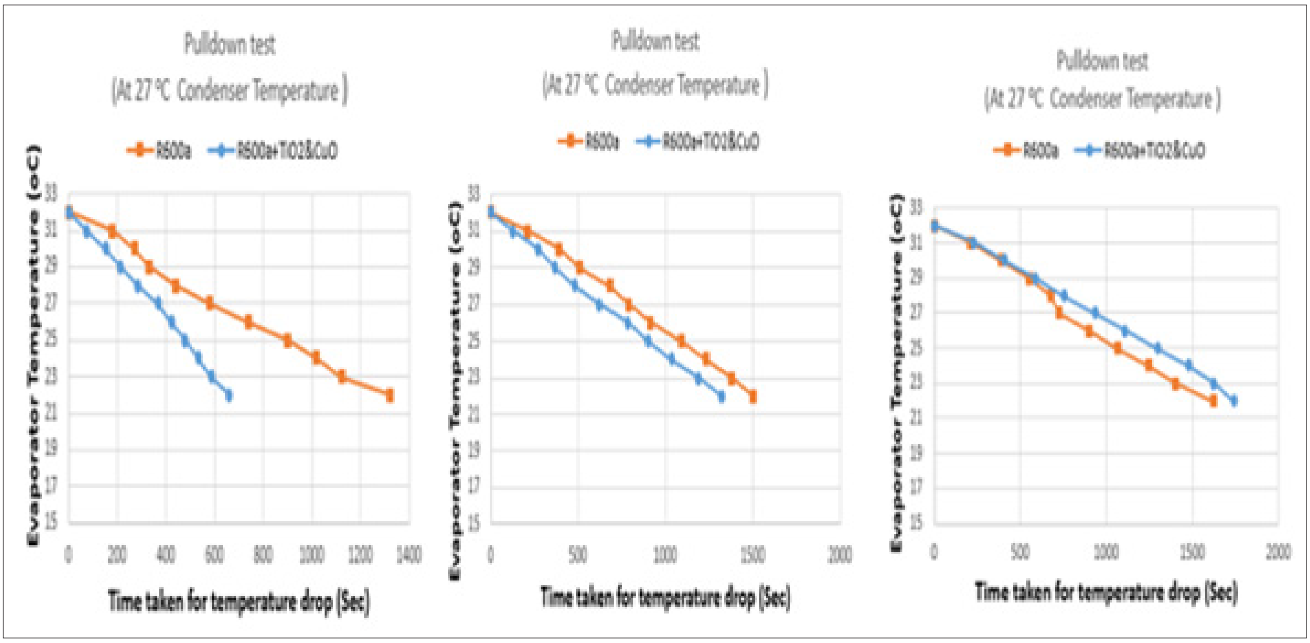

Figure 3: Pulldown test results at 270 ^{0}C condenser operating temperature for a capillary length of (a) 8 feet (b) 10 feet, and (c) 12 feet.

ated with TiO_2 and CuO composite nano material for a condenser temperature of 33 ^{0}C and 37 ^{0}C at variable capillary tube lengths of 10 and 12 feet were shown in Figure 4 and Figure 5.

The performance of the VCR system can be expressed as ratio of refrigeration effect to work done.

Coefficient of Performance (COP) =

$$\frac{Refrigeration\ effect}{Work\ Done} = \frac{m\ Cp\ \Delta T\ /\ time}{Power\ Supplid\ to\ Compressor}$$

Where, m = Quantity of water to be cooled in kg,

C_p = Specific heat of water = 4180 kJ kg^{-1} K^{-1}

$\Delta T\ /\ time$ = Temperature-drop with respect to time

The refrigeration effect is the quantity of cooling effect produced in evaporator in watts and the power consumption can be noted directly from the watt meter in watts. The ratio of these two will give the COP of the system. The experimental results obtained with R600a as refrigerant and R600a with nanoparticles were tabulated in Table 3, Table 4 and Tables 5 for the capillary tube length of 8, 10 and 12 feet, respectively.

From the experimental values, it was observed that, for R600a refrigerant at the condenser temperature 27 °C the refrigeration effect was found to be 222 W and power consumed was 210 W. The COP was found to be 1.05. Whereas, for R600a with TiO_2 and CuO the refrigeration effect produced was 444 W and power consumed is 195 W. The COP was found to be 2.27.

Table 2: Experimental observations at various ambient temperatures and different length of capillary tubes for R600a with TiO_2 and CuO.

L	Ambient	T_1	T_2	T_3	T_4	T_5	P_d	P_s	W	Time
8	27 ^{0}C	31.6	44.9	42.7	13.2	22	3.90	1.69	211	660
8	33 ^{0}C	34.8	47.2	45.0	15.9	22	4.29	1.88	209	720
8	37 ^{0}C	36.7	51.6	49.4	18.0	22	4.79	2.18	209	646
10	27 ^{0}C	31.6	42.5	40.4	12.5	22	3.71	0.90	198	1320
10	33 ^{0}C	36.1	48.9	46.8	13.2	22	4.34	1.20	194	1133
10	37 ^{0}C	36.5	50.0	48.0	12.3	22	4.50	1.25	195	1080
12	27 ^{0}C	31.9	44.2	42.2	9.0	22	3.73	0.55	199	1740
12	33 ^{0}C	35.1	48.3	46.1	11.2	22	4.20	0.77	207	1920
12	37 ^{0}C	38.3	51.7	49.5	13.2	22	4.57	1.02	213	1620

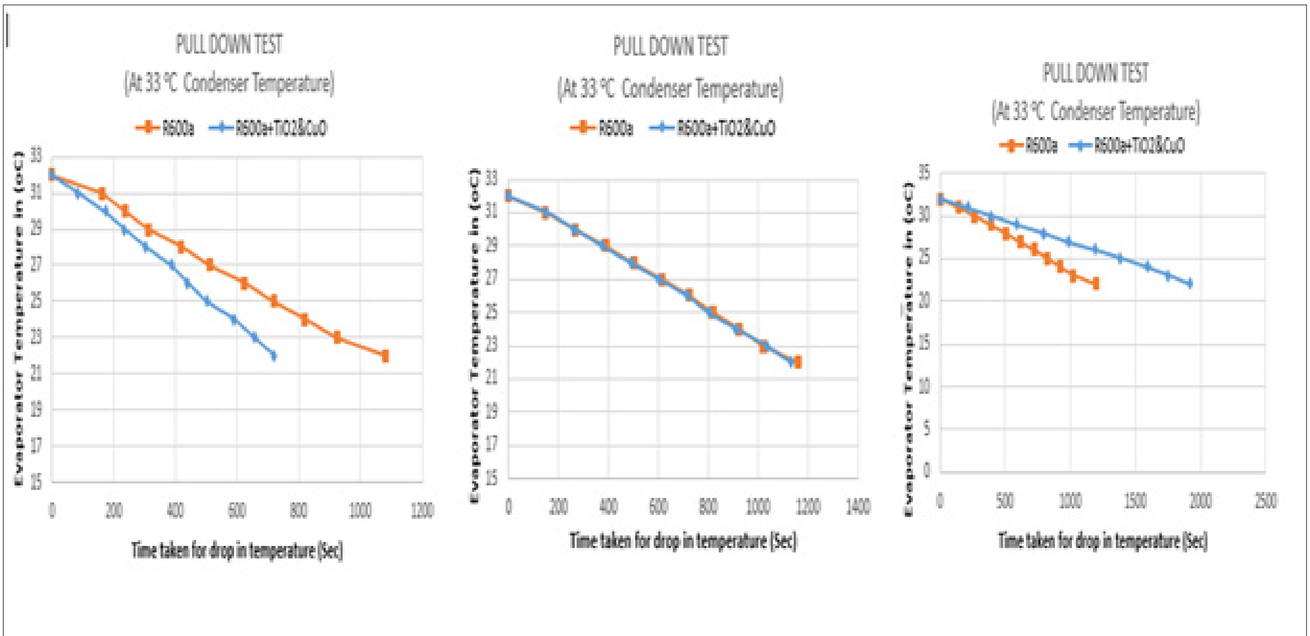

Figure 4: Pulldown test results at 33 ^{0}C condenser operating temperature for a capillary length of (a) 8 feet (b) 10 feet, and (c) 12 feet.

Table 3: R.E, Power, and COP at various ambient conditions for 8 feet long capillary tube.

T	Refrigeration Effect R600a (watt)	Refrigeration effect R600a+TiO_2 and CuO (watt)	Power consumption-R600a (watt)	Power Consumption R600a+TiO_2 and CuO (watt)	COP R600a	COP R600a+ TiO_2 and CuO
27 °C	222.0	444.00	210	195.0	1.05	2.27
33 °C	271.3	407.00	209	195.0	1.29	2.08
37 °C	183.3	452.94	209	183.3	0.87	2.47

At the condenser temperature 33 °C the refrigeration effect was found to be 271.3 W and power consumed was 195 W. The COP was found to be 1.3. At the condenser temperature 37 °C the refrigeration effect was found to be 183.3 W and power consumed was 200.7 W. The COP was found to be 0.91.

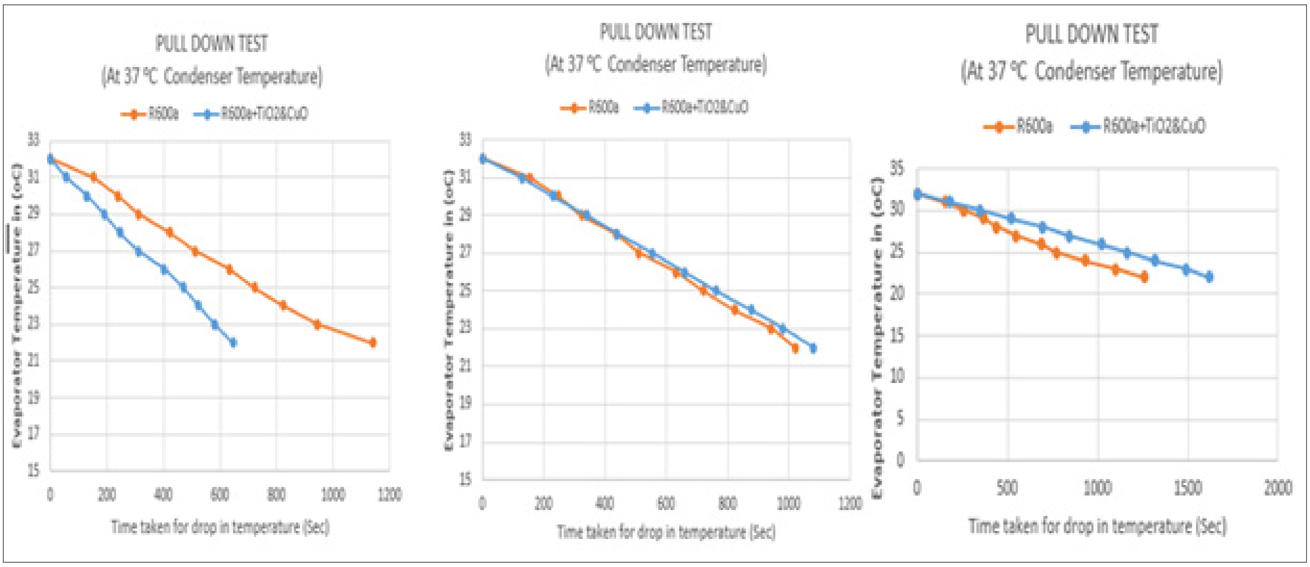

Figure 5: Pulldown test results at 37 ^{0}C condenser operating temperature for a capillary length of (a) 8 feet (b) 10 feet, and (c) 12 feet.

Table 4: R.E, Power, and COP at various ambient conditions for 10 feet long capillary tube.

T	Refrigeration Effect R600a (watt)	Refrigeration effect R600a+TiO_2 and CuO (watt)	Power consumption-R600a (watt)	Power Consumption R600a+TiO_2 and CuO (watt)	COP R600a	COP R600a+ TiO_2 & CuO
27 °C	195.30	222.00	190.00	197	1.03	1.30
33 °C	252.20	258.00	193.00	195	1.30	1.32
37 °C	287.00	271.00	219.00	191	1.31	1.40

Table 5: R.E, Power, and COP at various ambient conditions for 12 feet long capillary tube.

T	Refrigeration Effect R600a (watt)	Refrigeration effect R600a+TiO_2 and CuO (watt)	Power consumption-R600a (watt)	Power Consumption R600a+TiO_2 and CuO (watt)	COP R600a	COP R600a+ TiO_2 and CuO
27 °C	180	166	191	199	0.91	0.84
33 °C	244	152	188	204	1.29	0.74
37 °C	232	180	187	211	1.24	0.85

From Figure 6, it was evident that refrigeration effect produce was higher in case of added nanoparticles than pure R600a. This improvement was due to existence of nanoparticles in the refrigerating circuit. The lubricating oil of compressor travels with the refrigerant into the entire refrigerant circuit. The nanoparticles also reach the inside surface of the evaporator along with the oil, which increases heat transfer rate in the evaporator and the cooling effect too. As the capillary length increases from 8 feet to 12 feet the cooling effect produced was decreases for a refrigerant with added nanoparticles and increases for pure R600a refrigerant due to volatility of refrigerant increases and as the length of capillary was more, the friction factor was more, thereby after expansion process more refrigerant will be evaporated and net cooling effect produced decreases.

The power consumption for varies capillary tube lengths at different condenser operating conditions was shown in Figure 7. The power consumption for nano refrigerant was reduced by 8.74% for a capillary length of 8 feet when compared to normal R600a refrigerant. Whereas the power consumption for 10 feet capillary length was reduced by 12.78% for nano refrigerant, when compared to normal refrigerant and for a capillary length of 12 feet the power consumption was increased by 12.83% for nano refrigerant, when compared to normal refrigerant as increase in capillary length will increases the friction coefficient factor and leads to increase in specific volume of refrigerant and hence the quantity handled by the compressor.

The COP is directly proportional to refrigeration effect

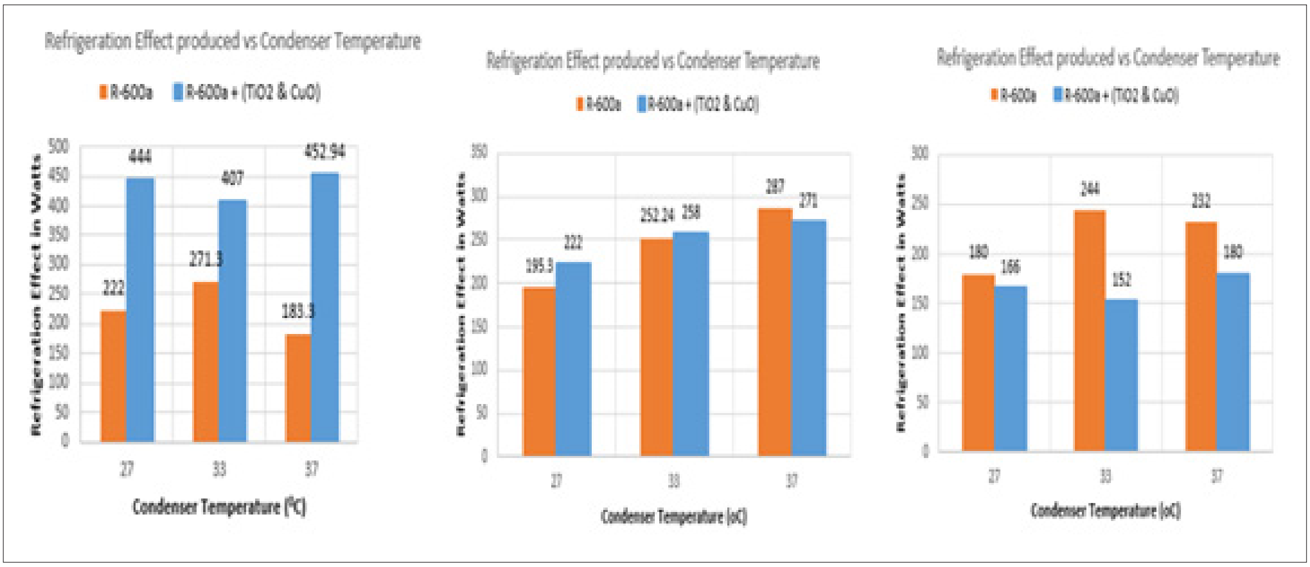

Figure 6: Refrigeration effect produced at different condenser operating temperatures for a capillary length of (a) 8 feet (b) 10 feet, and (c) 12 feet.

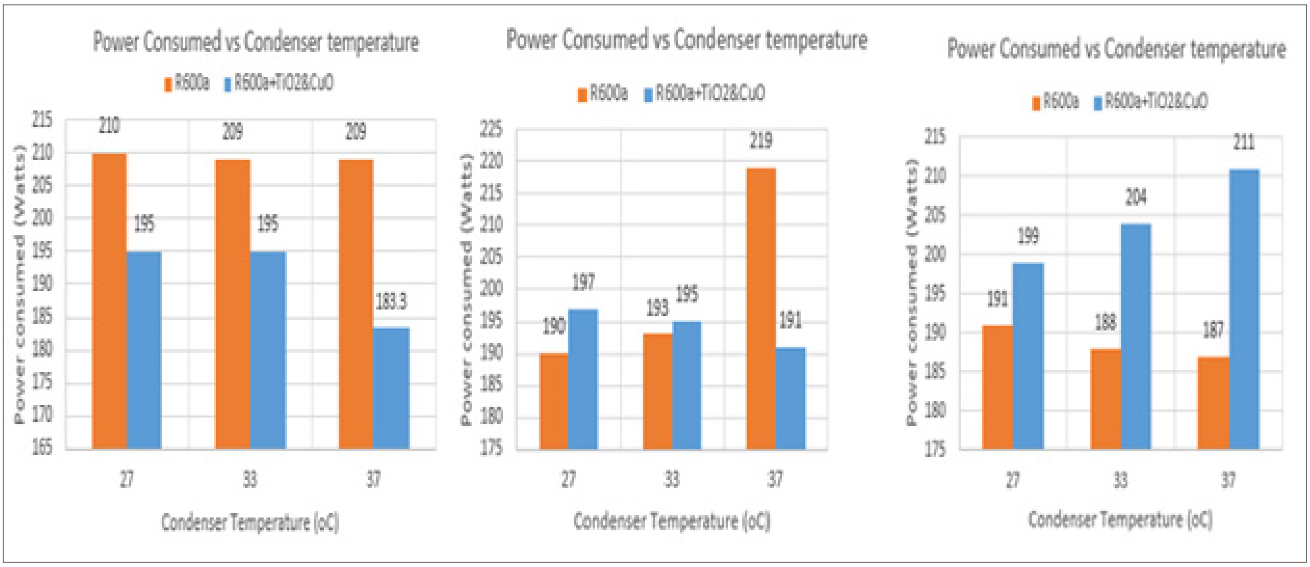

Figure 7: Power consumed at different condenser operating temperatures for a capillary length of (a) 8 feet (b) 10 feet, and (c) 12 feet.

produced and indirectly proportional to power supplied to the compressor, performance of 8 feet capillary was increased by 119.7% for nano refrigerant compared to normal R600a refrigerant and the details were furnished in Figure 8.

As the Capillary length was increased from 8 to 10 feet and 12 feet the percentage rise in COP value getting decreases as the refrigeration effect was decreased and power consumption values increases.

Conclusion

The effect of nanoparticles suspended in mineral oil on the performance of vapour compression refrigeration system was experimentally studied for a capillary length of 8 feet, 10 feet and 12 feet at a condenser operating temperature of 27 ^{0}C, 33 ^{0}C, and 37 ^{0}C. The nanoparticles enhances the thermal properties of refrigerant and there by increases the rate of heat transfer in the evaporator. The increase in capillary length affects the refrigeration effect produced in the evaporator, As the capillary length increases, the frictional coefficient factor was also increasing and there by decrease in refrigeration effect produced and increase in power consumption.

i) The refrigeration effect produced by nano refrigerant in 8 feet capillary length was doubled, compared to normal R600a refrigerant and decreases with increase in capillary length.

ii) The power consumption by compressor with added nanoparticles for 8 feet capillary length was decreases by

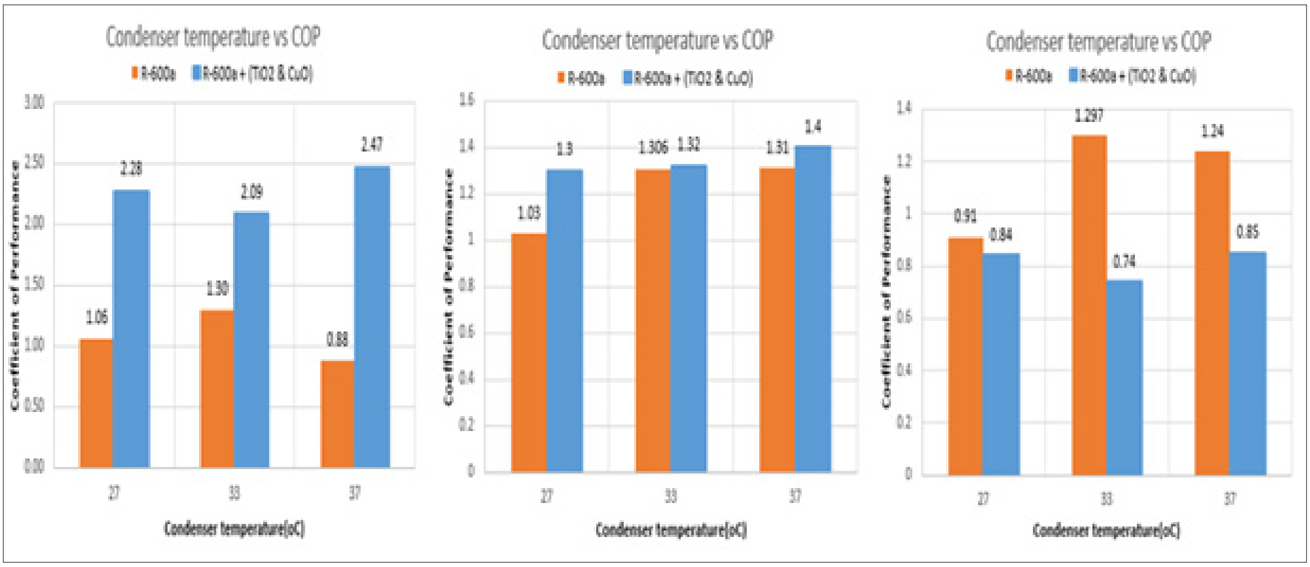

Figure 8: COP of VCR system at different condenser operating temperatures for a capillary length of (a) 8 feet (b) 10 feet, and (c) 12 feet.

7.14% and increases in power consumption for 10 feet and 12 feet capillary lengths.

iii) The performance of the system was increased by 115.94% with added nanoparticles at 8 feet capillary tube length and its value get decreases for subsequent capillary lengths of 10 feet and 12 feet.

iv) It was evident that a capillary tube length of 8 feet was suggestible when nanoparticles were used in lubricating oil for the enhancement COP of the refrigeration system.

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